Comparison of methods for evaluating the electromagnetic shielding of textiles

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COMPARISON OF METHODS FOR EVALUATING THE SHIELDING EFFECTIVENESS OF TEXTILES

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Abstract: Materials with electromagnetic shielding efficiency are widely used to attenuate the strength of electromagnetic fields as functional elements in electrotechnic devices and also as supporting elements for electromagnetic interference reduction. One of modern application is not only technical protection, but also protection of human being while operating specific electric equipments. In these days, instead of metallic shields it is more common to use various types of textile materials due to their desirable flexibility and lightweight. The results of shielding effectiveness measurements depend on the method, frequency and properties of the material itself. The current state of work in the field of standardization and measurement methods for the shielding effectiveness of thin planar materials is presented in this paper. Testing of textile samples shielding was performed by different methods and scope of application, their limitations and possibilities for comparison of results are discussed.

1 INTRODUCTION

According to World Health Organization [1], exposure to electromagnetic fields is not a new phenomenon. However, during the 20th century, environmental exposure to man-made electromagnetic fields has been steadily increasing as growing electricity demand, ever-advancing technologies and changes in social behavior.

Due to rapid development in commercial, military, scientific electronic devices and communication instruments, there has been an increased interest in developing materials that could shield against electromagnetic radiation to prevent interference.

Metal is considered to be the best electromagnetic shielding material due its conductivity and permeability, but it is expensive, heavy, and may also have thermal expansion and metal oxidation, or corrosion problems associated with its use. In contrast, most synthetic fabrics are electrically insulating and transparent to electromagnetic radiation [2].

In recent years, conductive fabrics have obtained increased attention for electromagnetic shielding and anti-electrostatic purposes. This is mainly due to their desirable flexibility and lightweight. One way how conductive fabrics can be created is by using minute electrically conductive fibers. They can be produced in filament or staple lengths and can be incorporate with traditional non-conductive fibers to create yarns that possess varying degrees of conductivity. Another way represents conductive coatings which can transform substrates into electrically conductive materials without significantly altering the existing substrate properties. They can be applied to the surface of fibers, yarns or fabrics. The most common are metal and conductive polymer coatings.

Whilst we are able to determine shielding effectiveness for metal shield just by knowing the materials' electrical magnetic parameters, for materials containing inserted metallic or graphite threads, metalized surfaces or composite materials, it seems we are able to determine the shielding effectiveness by actually measure it [4].

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2 ELECTROMAGNETIC SHIELDING MEASUREMENT METHODS

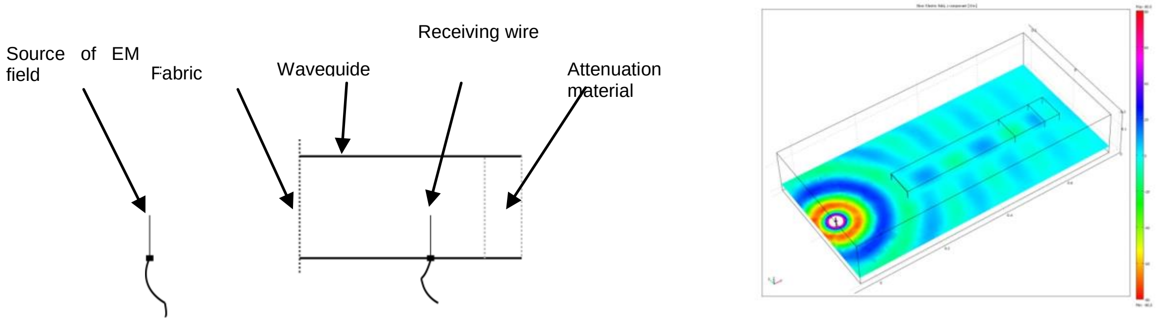
There are several methods available for shielding effectiveness (SE) measurement. However, for thin planar structures, there are no standards defining the evaluation of small samples of only a several tens of centimeters in size. The following test methods are commonly used to measure electromagnetic shielding of a given shielding material.

1. Shielded box method
2. Shielded room method
3. Coaxial transmission line method
4. Waveguide method – modified shielded box method

Each of mentioned method has some advantages and limitations. For example coaxial transmission line method (ASTM D4935) is now the preferred method. The measurements can be made at specific frequency range (from 30 MHz to 1.5 GHz). The results obtained in different laboratories should be comparable [5]. Tests are carried out on small doughnut shaped samples, but preparation of samples is quite time consuming.

MIL-STD-285, IEEE-STD-299 and later standards (e.g. EN 61000-5-7) are based on the shielded room method, are marked as the most sophisticated ones [3], but test specimen size is typically of the order of 2.5 m^2 in area. In general, a signal source is place outside the test enclosure, whilst the measurement device is located inside. Frequency range is about 100 kHz to 10 GHz. It is expected [4] that the test results obtained for the same material tested at different laboratories can vary, even by as much as several dB. This is because the opening in the shielded wall of the chamber also affects the measurements. This opening itself forms a type of antenna with the parameters depending of several factors, one of which is its dimension.

Waveguide method was developed during this research. Basic parts of device are two waveguides. One waveguide is connected with receiving wire (antenna). Textile sample is placed on the entrance of second waveguide. The end of this waveguide is filled by foam saturated by carbon absorbing the electromagnetic field passed through sample. Sample is oriented perpendicularly the electromagnetic waves. Transmitting antenna is placed in front of first waveguide input. This method overcomes the limitations of shielded box method. No special preparation of test samples is necessary, but for particular frequency range a waveguide with specific dimensions is required.



a) *b)*

Figure 1: a) Scheme of device for measurement of electromagnetic shielding efficiency (based on waveguide method), b) simulation of electromagnetic wave entering the waveguide.

The electromagnetic interference shielding efficiency measurement needs to use special devices. Simpler are measurements of electric characteristics of sample. It is known from theory that at sufficiently high frequencies in is possible to measure characteristics of electrical part of electromagnetic field only and therefore it should be mathematical relation between total shielding effectiveness and fabric resistivity or conductivity [6].

Basic proposed numerical models of fabrics SE are based either on electrical properties (especially volume conductivity) of element [7-12] or on analysis of leakage through of opening in textile [13].

Shielding effectiveness S_T of the conductive materials can be expected by the following expression [8, 9]

$$S_T = 50 - 10\ \log\left(\frac{f}{K}\right) + 1.7\ t\ \sqrt{f\ K} \tag{1}$$

where K [S cm^{-1}] is the volume conductivity of the conductive material and f [MHz] is the frequency.

The usefulness of this model can be ascertained by comparison with the model of White [7], which is usually used to predict the shielding effectiveness of a conductive sample of thickness t [cm] to an electromagnetic wave of frequency f (Hz), given as

$$S_T = 168 - 10\ \log\left(\frac{K_c f}{K}\right) + 1.315\ t\ \sqrt{\frac{K}{K_c} f} \tag{2}$$

where K [S cm^{-1}] is the volume conductivity and K_c is copper conductivity (5.82 10^5 S cm^{-1}).

The analysis of leakage through openings in conductive yarn fabric shields is based on transmission line theory [13]. The shielding effectiveness is given by the equation

$$S_T = A_a + R_a + B_a + K_1 + K_2 + K_3 \tag{3}$$

where A_a [dB] is attenuation introduced by a particular discontinuity, R_a [dB] is a fabric aperture with single reflection loss, B_a [dB] is a multiple reflection correction term, K_1 [dB] is a correction term to account for the number of like discontinuities, K_2 [dB] is a low-frequency correction term to account for skin depth and K_3 [dB] is a correction term to account for a coupling between adjacent holes. The empiric relations for these attenuation are published e.g. in the work of Perumalraja [1]. Only in the evaluation of term K_2 is an implicit knowledge of the electrical characteristics (conductivity and permeability) of the fabric required. Since this term is valid only for low frequencies [11] it has been omitted from the calculation at microwave frequencies.

In order to approximate the mesh nature of the fabrics the following assumptions are used:

1) The conductive fibers are wound together in a bundle in the center of the bundle of nonmetallic fibers. These two bundles together form the fabric strands.

2) The only influence of the nonmetallic fibers is to space the bundles of metallic fibers apart.

3) The pores in the fabric are square.

For effective shielding the fabric it should contain as few portions of pores as possible.

The shield effectiveness S_T of materials with (carbon) filler depends on the volume percent of the filler material V [%] [14]

$$ST = 2.46\ V \quad (4)$$

For a single conductive layer, the theoretical value S_T can be written as [10]

$$S_T = 20\ \log\left(1 + \frac{K\ t\ Z_o}{2}\right) \quad (5)$$

where K is conductivity; t, the thickness of the sample; and Z_0, the free-space wave impedance, 377Ω. For low electrically conductive materials are these models not useful [10].

Another way is utilization of knowledge of materials complex permittivity. Attenuation of electromagnetic wave in material is possible to calculate from this value. The amount of attenuation due to shield depends on the electromagnetic waves reflection from the shield surface, absorption of the waves into the shield and the multiple reflections of the waves at various surfaces or interfaces in the shield. Following relationships stand for electric part of electromagnetic wave. Similar formulas stand for magnetic part:

$$\vec{E}_r = R\vec{E}_d\ , \quad (6)$$

$$\vec{E}_t = T\vec{E}_d, \quad (7)$$

where R coefficient of reflection and T coefficient of transmission are:

$$R = \frac{Z_2 - Z_1}{Z_1 + Z_2}\ , \quad (8)$$

$$T = \frac{2Z_2}{Z_1 + Z_2}\ , \quad (9)$$

where Z_1, Z_2 are characteristic impedance of air, resp. sample. A characteristic impedance of surroundings can be calculated from:

$$\hat{Z} = \sqrt{\frac{\mu}{\hat{\varepsilon}}} \quad (10)$$

where $\hat{\varepsilon}$ is complex permittivity of surroundings, μ is relative permeability.

3 EXPERIMENTAL

3.1 Hybrid Fabrics

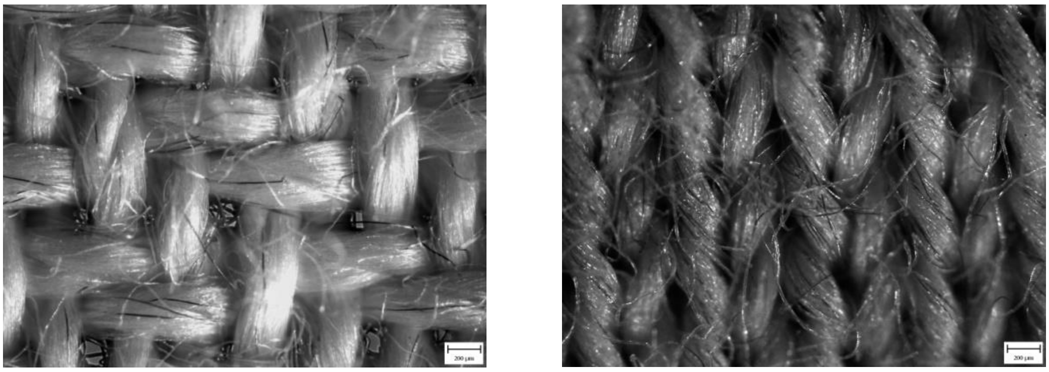
Four special textile samples were studied. Samples with different structure (woven, knitted) and different content of conductive component (stainless steel fiber) were chosen for this experiment from extensive sample set prepared in previous work [15].

Hybrid fabrics were composed of hybrid yarns containing polypropylene and different content of staple metal fiber. The aspect ratio (length/diameter ratio, l/d) of the SS is 6250 used in this study, since the diameter of the SS is 8 μm and the fiber length of the SS is 50 mm. Details about studied fabrics are given in the Table 1. Microscopic figures of chosen studied samples are at Figure 2.

Table 1: Studied fabrics details

Sample	Structure	Composition	Thickness [mm]	Yarn fineness [tex]	Mass per unit area [g/m^2]
1	woven - twill	80% POP/ 20% SS	0.71	50	220
2	woven – twill	95% POP/ 5% SS	0.77	50	220

3	woven - twill	99% POP/ 1% SS	0.78	50	220
4	knitted – flat stitch	90% POP/ 10% SS	0.64	25	182



(a) (b)

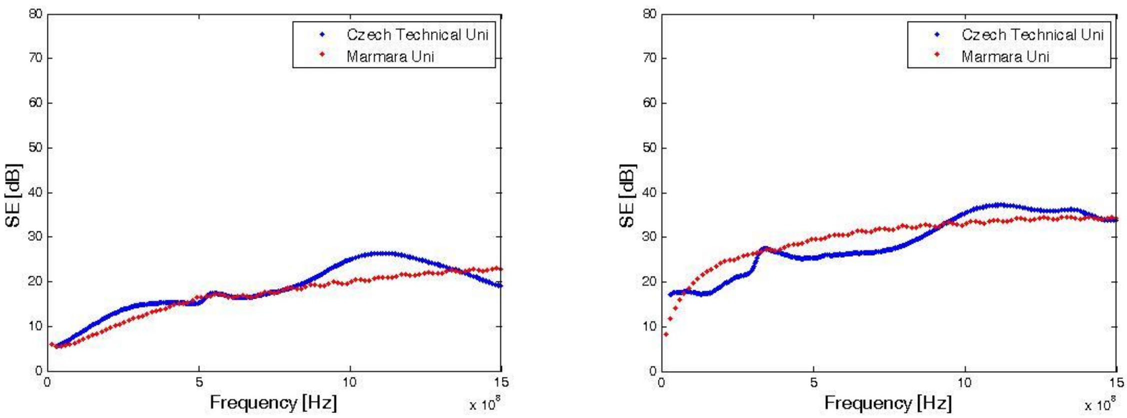
Figure 2: Microscopic images of chosen studied fabrics: a) sample 2, b) sample 4.

3.2 Characterization

Electromagnetic shielding efficiency of textiles sample set was measured by 3 different methods. These methods comprise coaxial transmission line method based on ASTM D4935 performed at two different laboratories – at Marmara University in Turkey and Czech Technical University in Prague, shielded room method (EN 61000-5-7) in certified lab VOP Šternberk and waveguide method at similar frequency range. Possibilities of modeling electromagnetic shielding efficiency based on electric properties of samples were verified. Specifically models based on volume resistivity (White model [7]) and complex permittivity were verified. Result were compared, findings and recommendations are discussed.

4 RESULTS AND DISCUSSION

You can see comparison of results measured by coaxial transmission line method for the same textile samples at Figure 3. It is clear that the curves are not exactly the same, but they are comparable. This can be caused by different modification of samples before measurement (in one case, paper was mounted on textile to cause easier preparation of samples), sample holder used in Czech Technical University was not commercial (it was prepared according to the standard by researchers), screws were not used at Marmara Uni measurement (change in impedance).



a) *b)*

Figure 3: Comparison of measurement by transmission line method at two different laboratories: a) sample no. 2, b) sample no. 1.

Comparison of shielding efficiency results measured by different methods (coaxial transmission line method measured at two different laboratories, shielded room method, waveguide method) for the same sample is shown at Figure 4. It is clear that results given by shielded room method (standard EN 61000-5-7) vary widely from other results.

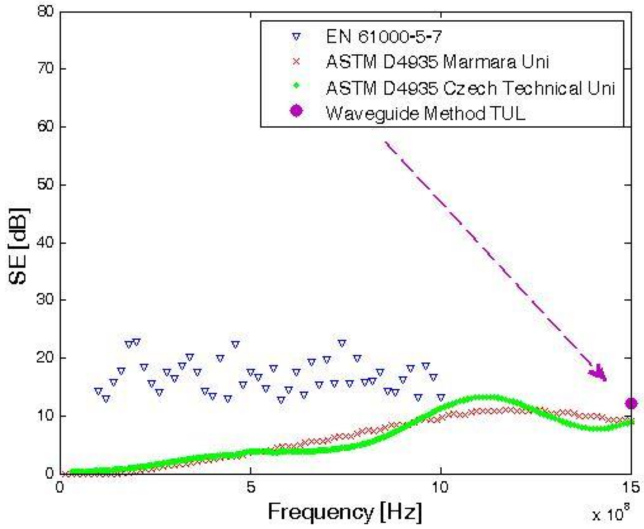


Figure 4: Comparison of shielding effectiveness measured by different methods – sample no. 4.

Comparison of results measured by coaxial transmission line with results calculated based on knowledge of electrical properties (volume resistivity, complex permittivity) for the same textile sample is shown at Figure 5.

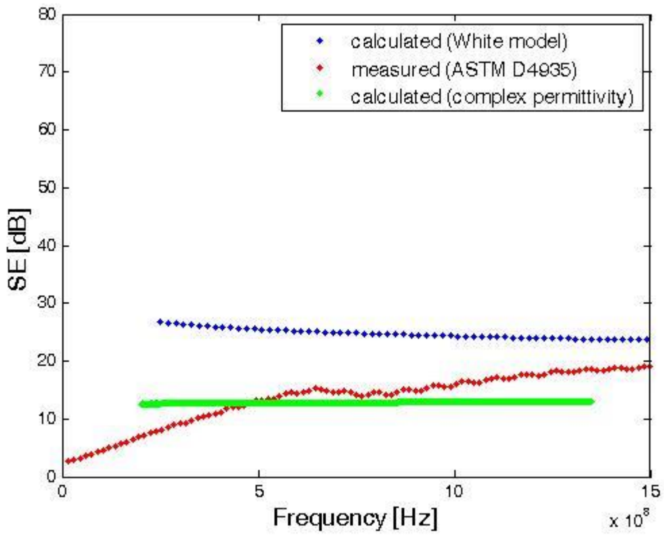


Figure 5: Comparison of measured shielding effectiveness prediction of a shielding efficiency based on electric conductivity knowledge – sample no. 3.

5 CONCLUSION

It was found out that results obtained by coaxial transmission line method at two different laboratories are comparable. It is clear that the shielding effectiveness measurement results obtained using currently known methods based on different principles depend not only on the parameters of the material, but also on the size of the test sample, the geometry of the test setup and the parameters of the source of electromagnetic radiation and there is a lack of generally accepted standardized methods for measuring shielding effectiveness. Therefore the same measurement method and the same test setup geometry should be always used to be able to compare and evaluate a shielding of material. Also, when presenting research results, one should specify the measurement method used in study.

Another way how to find out shielding efficiency of textile samples is calculation based on knowledge of electrical properties of samples. Two basic approaches were demonstrated. The results are comparable with data obtained by ASTM D4935.

Acknowledgement

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References

[1.] World Health Organization, Establishing a Dialogue on Risks from Electromagnetic Fields, Geneva, Switzerland, 65p., 2002. ISBN 92 4 154571 2.

[2.] CHENG, K., B., et al., Effects of Yarn Constitutions and Fabrics Specifications on Electrical Properties of Hybrid Woven Fabrics, Composites: Part A 34, 2003.

[3.] GEETHA, S., et al. EMI shielding: Methods and Materials - A Review. *Journal of applied polymer science*. 2009, 112, s. 2073-2086.

[4.] WIECKOWSKI, T. W., JANUKIEWICZ, M. J., Methods for Evaluating the Shielding Effectiveness of Textiles, [online], [2009], URL:< http://www.fibtex.lodz.pl/59_09_18.pdf>.

[5.] VOJTĚCH, L., HÁJEK, J., Measurement of electromagnetic shielding efficiency of planar textiles in frequency range 100 kHz – 1.5 GHz. Acces server [online]. 2010, vol. 8, no. 3. Internet: http://access.feld.cvut.cz/view.php?cisloclanku=2010030006. ISSN 1214-9675. (in Czech).

[6.] SAFAROVA, V.; MILITKY, J. Corelation between resistance and electromagnetic shielding of hybrid weaves. In *Aachen Dresden International Conference : Book of abstract*. Dresden : Technical University Dresden, 2010. s. 5. ISBN 978-4-901381-32-1.

[7.] WHITE, D.R.J.: *A Handbook Series on Electromagnetic Interference and Compatibility*, Vol. 5, Don White Consultants, Germantown, MD (1971).

[8.] SIMON, R. M. Conductive plastics for EMI shielding, in Thirty-Eighth Annual Technical Conference, p. 207 (1980).

[9.] SHINAGAWA, S. Conductive papers containing metallized polyester fibers for electromagnetic interference shielding, J. Porous Materials 6, 185–190 (1999)

[10.] COLANERI, N. F., SHACKLETTE, L. W., IEEE Trans Instrum. Meas., 41, 291(1992) .

[11.] CHEN, H. C., Fabrication of conductive woven fabric and analysis of electromagnetic shielding via measurement and empirical equation, Journal of Materials Processing Technology, 184, 2007.

[12.] VOJTĚCH, L., NERUDA, M, HÁJEK, J., Planar materials electromagnetic shielding efficiency derivation, International Journal on Communications Antenna and Propagation. 2011, vol. 1, no. 1.

[13.] PERUMALRAJA, R., Electromagnetic shielding effectiveness of copper core-woven fabrics, J. Text. Inst. 100, 512–524 (2009)

[14.] KEITH J. M. et all. : Shielding Effectiveness Density Theory for Carbon Fiber/Nylon 6, 6 Composites, *Polym. Compos*., **26,** 671–678, (2005)

[15.] MILITKÝ, J. a V. ŠAFÁŘOVÁ. Numeridal and Experimental Study of the Shielding Effectiveness of Hybrid Fabrics. *Vlákna a textil*. 2012, vol. 19, no. 1, s. 7. ISSN 1335-0617.